BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 06031

SUBJECT: Potential of Dual Purpose Expendable Cryogenic Stage as Replacement of the Saturn V - Case 105-6

DATE: June 10, 1970

FROM: J. J. Schoch

ABSTRACT

The performance of a dual purpose expendable cryogenic stage was calculated. Such a stage, called stage x, could serve as either the first stage of a two stage vehicle that uses the SIVB as a second stage or as the second stage of the space shuttle. In the first case it would be an interim replacement of the Saturn V; in the second, a final replacement.

Limiting the weight of stage x plus payload to the weight of a standard orbiter results in a payload of 228,000 lb using a 50,000 lb payload shuttle booster or 146,000 lb using a 25,000 lb payload shuttle booster. However, when this same stage x is used as a booster with a modified SIVB as second stage, the payload to earth orbit is only 72,000 lb or 54,000 lb respectively.

Extending the performance calculations to cover a wide range of stage x weights indicates that, if the booster vehicle is capable of carrying a second stage that is heavier than the standard orbiter, a dual purpose high mass fraction cryogenic stage is feasible. The 25,000 lb shuttle booster and a stage x of 800,000 lb gross weight would put a 170,000 lb payload in earth orbit. This same stage would place up to 95,000 lb in earth orbit when used with a modified SIVB second stage.

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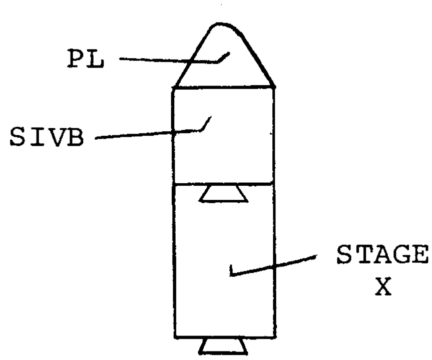
MEMORANDUM FOR FILE

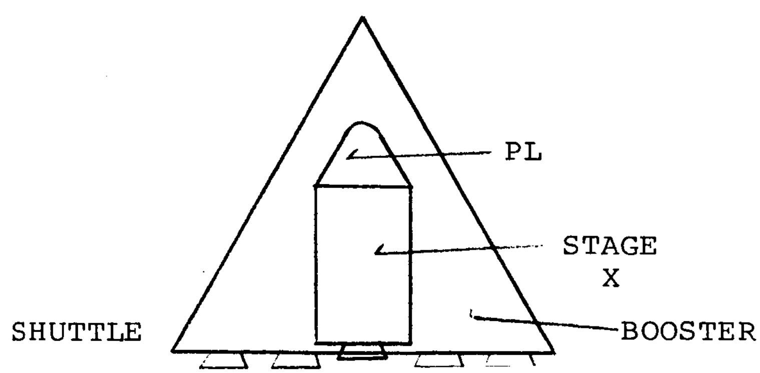
INTRODUCTION

Space Shuttle concepts have been built around requirements for 25,000 lb and 50,000 lb to 270 nm, 55° earth orbit and the use of two stage reusable vehicles. In both cases it has been suggested that payload limits may be increased by replacing the reusable orbiter stage with an expendable stage. Since the shuttle orbiter's mass fraction is low, about 0.68, an expendable high mass fraction stage could easily provide payloads in excess of 100,000 lb. Although this could be accomplished with the SIVB stage, a study described in reference 1 showed that the low thrust to weight ratio of the SIVB necessitates launch trajectories which result in much greater reentry g loading, heating rate, and flyback range for the booster. Modifying the launch trajectory to correct for these problems reduces the theoretical payload by as much as 25 to 30 percent.

The following describes the use of a dual purpose expendable cryogenic stage. This stage, called stage x, could conceivably be either the first stage of a two stage vehicle that uses the SIVB as second stage or the second stage of a shuttle.



INTERIM SATURN V REPLACEMENT



FINAL SATURN V REPLACEMENT

In the first case it could be an interim replacement of the Saturn V for launching large payloads in orbit; in the second, a final replacement.

STAGE X PERFORMANCE

The performance calculations were based on a stage x mass fraction $\lambda = 0.88$ and a specific impulse I_{sp}(vac) = 465 sec. The SIVB stage was also assumed to have an I_{sp}(vac) = 465 sec; i.e. the J-2 engine is replaced with the shuttle high pressure engine, but the tank size is unchanged. The results of the calculations are shown as dashed curves on Figure 1 on which payload is plotted vs the initial weight of stage x for various vehicles. The top curve represents the performance of a vehicle consisting of the General Dynamics 50,000 lb shuttle booster (Reference 2) and stage x used as a second expendable stage. For convenience it will be referred to as the 50,000 lb shuttle curve. The second curve was obtained by using stage x with the General Dynamics 25,000 lb shuttle booster. It will be referred to as the 25,000 lb shuttle curve. The lowest curve represents a vehicle using stage x as first stage and the SIVB as second stage. It will be called the SIVB curve.

Calculations resulting in these three curves are based on a total ideal ΔV = 30350 ft/sec, a figure obtained from the weight ratios and vacuum I_{sp} values of the General Dynamics 25,000 and 50,000 lb payload sequential burn shuttles to a 260 nm, 55° inclination orbit as given in Reference 2.

Points A on both the 25,000 and the 50,000 lb shuttle curves represent a stage x of such a size that its weight together with the payload is the same as that of the respective standard orbiters. A stage x of that size would make it possible to fly the same trajectory as would the standard shuttle. The payload is 226,000 lb with the 50,000 lb shuttle booster and 146,000 lb with the 25,000 booster. When used with the SIVB as a second stage, stage x is capable of delivering a payload of only 54,000 lb and 72,000 lb respectively.

It was next assumed that stage x plus payload, when used with the shuttle booster, could weigh more than the standard orbiter stage. The stage x size that provides the optimum ΔV split between the two stages i.e. the minimum gross liftoff weight for a given payload, was determined by the method described in Reference 3 for each case and is indicated on each curve by point B. It is seen that the point B vehicles and payloads are much larger than those of point A.

As mentioned previously the performance calculations represented by the dashed curves assume a total ideal ΔV value derived from the weight ratios of the shuttle. This implies that along these curves the ΔV losses are constant. The losses consist primarily of gravity losses, which are influenced by the thrust to weight ratio. As stage x increases in size, its thrust may be assumed to increase correspondingly. Therefore, second stage thrust to weight ratio for the upper two curves and first stage thrust to weight ratio of the lower curve can be maintained constant as stage x weight increases. If the thrust of the booster and the thrust of the SIVB were to increase appropriately with increasing stage x weight, the payload calculation represented by the dashed curves would be exact. In reality, the weight and thrust of the SIVB and the booster are fixed, and ΔV losses would be somewhat different from those used in the theoretical calculations. This difference in performance due to the decreasing booster thrust to weight ratio as stage x weight increases was determined for the 25,000 lb shuttle by running a few actual trajectories. The solid line ACD departing from point A on the 25,000 lb shuttle curve represents these calculations. The liftoff thrust to weight ratio, which is 1.4 for the conventional shuttle vehicle and at point A, decreases to 1.3 at point C and to 1.2 at point D. It is believed that point D approaches the lowest practical limit for liftoff thrust to weight ratio. It corresponds to a stage x weight of 820,000 lb plus a payload weight of 170,000 lb, or a total of almost 1,000,000 lb to be carried by the booster which is almost twice the normal weight of the orbiter. This size stage x is very close to that providing the optimum ΔV split with the SIVB second stage (point B on the SIVB curve). In that case it provides a payload of 95,000 lb.

Finally, to put these calculations within the framework of other studies, the results of the SIVB performance as a second stage for the shuttle booster are shown as point E. The two points indicate the payload with the 25,000 and 50,000 lb shuttle booster as given in Reference 1. Since the SIVB considered in Reference 1 has an I_{sp} of only 426 sec, the points are lower than the extrapolated dotted curves. Also, as explained in Reference 1, the optimum trajectory representative of the payload of points E gave such high aerodynamic loads for booster entry, that non-optimum trajectories had to be used thus degrading the payload to a value represented by the tip of the arrows.

As another example, an offloaded SII stage was used with the 25,000 lb shuttle booster. It is represented as point F. In this case, which essentially corresponds to one considered in a preliminary MSFC study, the center engine of the SII stage is replaced by an RL-10 to provide low thrust capability for orbit changes. Some propellant is offloaded in such a way as to maintain a 1.25 liftoff thrust to weight ratio. Propulsion was considered to be provided by conventional J-2 engines with I_{sp} = 426 sec. The aerodynamic entry g-load on the booster for this case is 5.23 without pitch modulation.

CONCLUSIONS

Assuming that the booster can carry a load that is heavier than the standard orbiter, a dual purpose high mass fraction cryogenic stage is feasible.

With the 25,000 lb shuttle booster, a stage x of over 800,000 lb would still have a liftoff thrust to weight ratio of 1.2. Such a vehicle would put payloads of over 170,000 lb in earth orbit. The same stage x with an SIVB stage would deliver a payload of 95,000 lb. Correspondingly higher payloads might be achieved with the 50,000 lb shuttle booster.

J J Schoch

1013-JJS-kle J. J. Schoch

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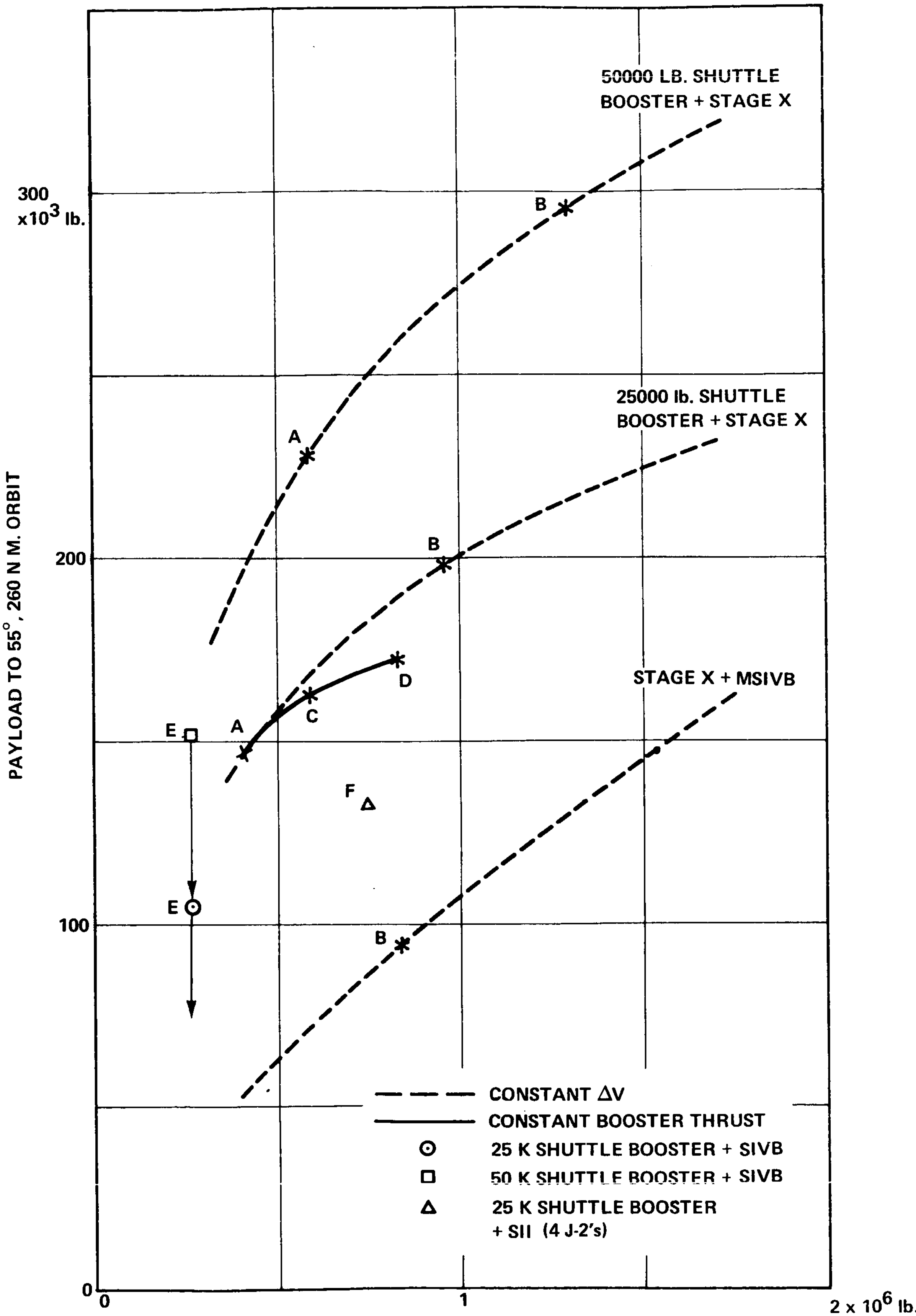
3. Bosch, H. B., and M. H. Skeer, "A Formula for Hand Computation in Two-Stage Vehicle Optimization," The Journal of the Aeronautical Sciences, Vol. XVI, No. 1, pp 38-39, Jan.-Feb. 1969.



INITIAL WEIGHT OF STAGE X (WITHOUT PAYLOAD).

FIGURE 1 - PERFORMANCE OF DUAL PURPOSE CRYOGENIC STAGE

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